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Analysis of Performance-based Fire Safety Evacuation in A College Library

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Abstract

Referring to the performance-based fire protection and safety evacuation, safety evacuation ability in a college library was analyzed. The fire loads and evacuation crowds of reading rooms was statistically analyzed with the on-the-spot Survey. The 4th reading room was considered as the most unfavourable evacuation area, and then it was reasonably simplified. The RSET (Required Safety Evacuation Time) was calculated according to experiential formulas, and ASET (Available Safety Evacuation Time) was determined by simulating room fire with field model FDS (Fire Dynamics Simulator). Then the evacuation ability of the 4th Reading-Room can be confirmed if RSET< ASET. Based on the analysis above, the fire protection and safety evacuation performance in the college library can be affirmed.

Keywords: College library, Fire, Safety evacuation, Performance-based design

1. Introduction

In recent years, university fires occur frequently, the fire-protection safety in the University Library also need urgent concern. Typically, the library is characteristic of dense fire loads, staff liquidity. Once fire occurs, not only property and human culture, and personal safety but also the threat of personal safety will be resulted. Furthermore, evacuation in library is very different from common buildings due to the special arrangement of the bookshelves [1]. Therefore, it is practically significant to research the how to evacuate quickly and safely during the fire emergency in the library.

Performance-based fire protection design has been gradually applied to the design of tunnel fire [2].As an important element of building fire protection, performance-based Safety evacuation design has got more attention, the relevant design methods and assessment techniques have been applied widely [3]. The ability of fire protection and safety evacuation in a university library was analyzed according to performance-based fire and safety evacuation design.

The library's common situation was as followed: 6 floors×4.5m, east-west 78m north-south 37.5m, with 4 zones of A, B, C and office zone, with a total area of 30,500 square meters. Reading-rooms and studying-rooms were located in Zone A, with a total of 1400 seats, which was the crowded place. The Plan and the distribution graphs were shown in Fig 1(a) and Table 1.

The number of entry was about 3000 person times/day. In normal circumstance, fire-prevention stairs in the east side were available, while in the west side was closed. Due to the various fire loads in the library, serious consequences would result once a fire occurred, meanwhile, safety evacuation in library has gradually became an important part of campus safety.

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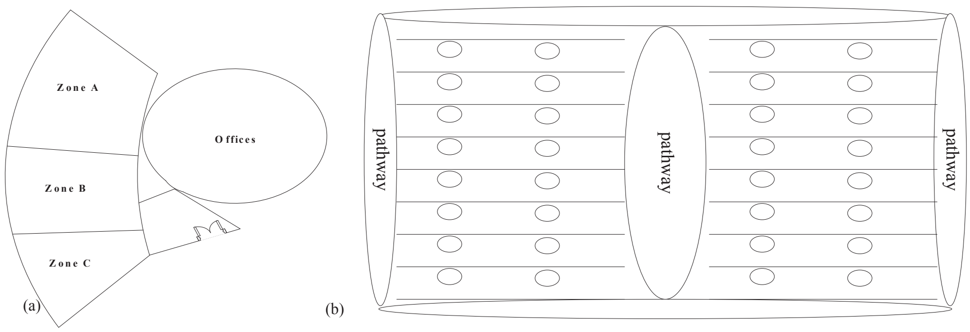

Fig.1. (a) Planar Graph of the Library (b) The model of safety evacuation (○– *human, horizontal bar –book shelve, zone between book shelves – a room modelled, Elliptic zone – pathway)*

Table 1. Distribution Map of the Library Collections

Floor distribution	6th Floor	Zone A: Teachers' Reading Room
	5th Floor	Zone A: 4th Reading Room
	4th Floor	Zone A: 3rd Reading Room
	3rd Floor	Zone A:2nd Reading Room
		Zone B: Audio-visual Room
		Zone C: Director's Office, Secretary Office
	2nd Floor	Zone A: Newspaper Reading Room, Book Return
		Zone B: E-Reading Room
		Zone C: Information Consultancy, Acquisition &Processing
	1st Floor	Zone A: Stack Room, 1st Reading Room

2. Survey and analysis on the element of fire-protection and evacuation

Through visiting and Survey of the library, it was found that students' reading rooms and studying rooms are the densest region, in which 1st, 3rd and 4th Reading Room, consisting lots of readers and book collection, is the key region for fire protection and safety evacuation. Therefore, through the detailed analysis of the three reading rooms, the performance of fire protection and Safety evacuation of libraries can be determined.

2.1. Survey of the areas of evacuation

The Size and disposition of book shelves, the area of different reading rooms and the book collections items was Investigated. The relevant data was shown as Table 2 and Table 3.

2.2. Survey and calculation of fire load density

Fire load density FLD (in MJm-2) is a key factor which should be studied carefully. The fire load density refers to the total heat emission of all combustible materials and room area ratio, i.e. quantity of heat within per unit area. Based on the data of relevant Literatures, the fire load density was calculated using empirical formula [4-6].

$$Q_f = \sum (M_i H_i) / A \tag{1}$$

To simplify the calculation, FLD was considered only the books'. The calorific value of the book was taken as 15MJ/m^2, calculated FLD of books was shown in Table 3.

Table 2. The size of book-shelf s in open-shelf Reading-rooms

Item	Size
column distance	105cm
Length of shelve	95cm
Width	20cm
Height	35cm

Table 3. The relevant parameter of Open-shelf Reading Rooms

Reading-Room	Total amount		Total mass（kg）		Floor area （m^2）	FLD(MJ/m^2)
	16K	32K	16K	32K		
1st	24108	23814	8322	6120	510.4	424
3rd	26978	26649	9313	6849	775.5	313
4th	34404	31913	11873	8202	688	437

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2.4. Survey and analysis of the number of evacuation

2.3.1 Survey

- Survey time and method

Each survey had three repeats for getting scientific data of evacuation crowds at different periods. The data were surveyed during the holiday and weekends that were expected to be the most unfavourable time for evacuation, when the crowds were expected to be higher. The time surveyed was respectively, the first day of May Day Holiday, Saturday and Sunday. Library opens between 8:00 and 21:00. The time of field Surveyed was from 8:00 to 19:00, the hourly data were recorded.

- Data surveyed

The average of three record values was applied as the result number. The data were listed as Table 4 and Fig 2..

Table 4. The reader number at different period

Period / Reading room	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
1st	23	82	146	140	74	55	76	125	145	148	104	142
3rd	14	27	50	50	34	28	35	48	55	48	36	47
4th	43	49	111	133	68	66	130	132	132	74	49	80

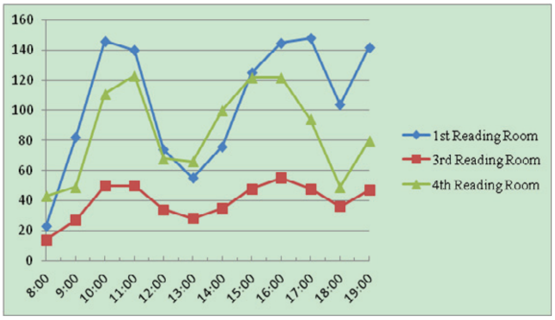


Fig.2. Distribution graph of reader number

In addition to the readers, the library staffs were surveyed. Of the total of 46 people aged 20 to 40 years old, more than 80% accepted fire-protection training possessing safety awareness.

2.3.2 Calculation and comparison analysis

Through the data above, it was found that 1st and 4th Reading-room were the unfavorable regions. The evacuation number should be theoretical calculated to analyze the practical performance. The formula was below

$$P = S \times a \times b \tag{2}$$

Referring to the relevant literature [7], the value of conversion coefficient b was 0.43, reduction coefficient a was 0.8. The data calculated and surveyed was compared in Table 5.

Table 5 shows that the maximum number surveyed is smaller than the calculated, which accords with Code of design on public building and Code of design on building fire protection and prevention.

Table 5. Data calculated and surveyed

Reading-room	Theoretical calculation	Maximum surveyed
1st	176	148
4th	237	133

3. Performance-based assessment on safety evacuation

3.1. Fire-protection safety target

The prime target of performance-based design is to ensure the safe evacuations of occupants [8]. Fire-protection safety target showed as follows:

(1) To reduce the injury and death of people (including the readers, staff, firefighters, etc.), and to Support the effective and rescue;

(2) To reduce the likelihood of fire, reduce property and economic loss;

(3) To prevent or delay the fire from spreading to other areas and adjacent buildings from spreading.

3.2. Evacuation model

By analysis of fire load, evacuation crowds and the route (4th Reading Room located at 5 floor), 4th Reading Room was the most unfavorable point for safety evacuation. Taking4th Reading Room as a case, detailed safety evacuation analysis based on performance was made.

The floor area is 688m^2(37 m×18 m×4.5 m), standard double-sided shelves, height 6 stalls (deep 0.45 m × length 1.00 m). Assuming the ratio of shelve-occupation was 100%, which was to say, all book-shelve were filled with books. The inter-row was 1.00 m; the main path was 3 m, and the walkway against wall 1m wide. An open exit was 1.80 m wide.

Considering the special structure of the shelves, the 4th reading room can be modeled as Several Evacuation rooms [9], as Fig 1(b) shown.

3.3. Fire scenario and fire Source

- Fire scenario

Fire scenario is the description of the whole developing process of certain fire, probability factors and determinate factors included [10]. Specific influence factor includes the layout of the building, fire load and distribution, the location of the fire source, the distribution and status of the person, and environmental factors, etc. To simplified calculation, fixed fire scenario was applied.

- Fire source

Automatic sprinkler system is equipped in the library, and t^2 non-steady fire source was chosen as the type.

a. Developing type

Fire developing coefficients are very different due to combustible materials. Usually, there are 4 types-slow, medium, fast, and ultra-fast. Increasing coefficient is showed in Table 6.

Increasing coefficient is calculated through formula (3) and (4)

$$\alpha = \alpha_f + \alpha_m \tag{3}$$

$$\alpha_f = 2.6\times10^{-6} q^{5/3} \tag{4}$$

Calculation was as followed.

$\alpha_f = 2.6\times10^{-6}\times485^{5/3} = 0.07784$, α=0.014+0.07784 = 0.09184 kw/s^2

Thus, it was fast fire.

Table 6. Types of t^2

Classification	Slow	Medium	Fast	Ultra-fast
Developing coefficient a（kw/s^2）	0.00278	0.01111	0.04444	0.1778
Time-constant（s）	600	300	150	75

b. Heat release rate

Heat release rate is considered as the single most important variable in characterizing the “flammability” of products and their consequent fire hazard [11]. Heat release rate reach its extreme value and as it develops to stable combustion stage.

Before the action of the automatic sprinkler system, the development followed the principle of t^2 non-steady, after the action, maximum value between the practical heat release rate and the authorized value of Code of smoke-control procedures in civil building (DGJ08-88-2000) was chosen as the extreme value that was 2.5MW.

3.4. The calculation of RSET (Required Safety Evacuation Time)

For simplifying, it was assumed as followed:

(1)All people had the same size, and good physical condition;

(2) People were uniformly distributed, and evacuated with a same and constant speed ;

(3)People perceived fire and begun evacuation at the same time, route reselect didn’t occur in the process; *RSET=Alarm time(Fire Detection Time)+ Pre-movement Time + Evacuation Movement Time.*

- Alarm time

Alarm time is the detection time of the detector, and it depends mainly on the flame shape, the temperature or the temperature rising rate, the concentration of products. The library is equipped with new temperature-smoke detector which can do rapid response. In the paper, it was 30s.

- Pre-movement Time

Statistical results show that Pre-movement Time has direct relation to Fire Alarm System. The library is equipped with favorable alarm system, including Audio broadcasting system and evacuation indicatory signs. Once a fire occurs, Fire Emergency Evacuation Broadcast System can start immediately.

According to the relevant literature [12-13], pre-movement time was 30-60s depends on the distance between person and fire source.

- Evacuation movement time.

According to the actual situation, RSET divided into 3 Periods.

a. Indoor movement time t_1

Occupant density of 4th reading room D= (readers 133 + staffs 4) person/688m^2=0.1991person/m2, in that condition, the person can walk in freedom.

The calculation was made through the following 3 formulas.

$$s = \pi(s_w - 0.429)/2 \tag{5}$$

$$t_1 = L/v \tag{6}$$

$$v = 1.4(1 - 0.266D) \tag{7}$$

L was the longest distance, including 2 converging curves whose determination was through formula (5). Then L was 34.5m. Through the formula (6) and (7), v=1.326m/s, t_1=26.02s.

b. Outlet passing time t_2

The width of outlet was a key influencing factor in safety evacuation. The Literature study proves that the effective width is 0.3m shorter than the actual width.

$$t_2 = P/F \times W \tag{8}$$

By calculation, t_2 was 57.08s.

c. Stairs passing time t_3

Stairs passing time was relevant to the number of person; the following empirical formula was applicable when crowd evacuation was down along the stairs.

$$W/P = 8.04/t_3^{1.37} \tag{9}$$

The calculated Value of $t_3$was 100.06s.

Thus, evacuation movement time, $t_m=t_1+t_2+t_3=183.16s$.

- Estimation of RSET

According to the calculation and analysis above, RSET= $t_a+t_p+t_m$=273.16s. Regarded to the influence of uncertain factors, the safety coefficient 1.5 was considered in the paper, then, RSET was estimated as 409.74s.

3.5. The estimation of ASET (Available Safety Evacuation Time)

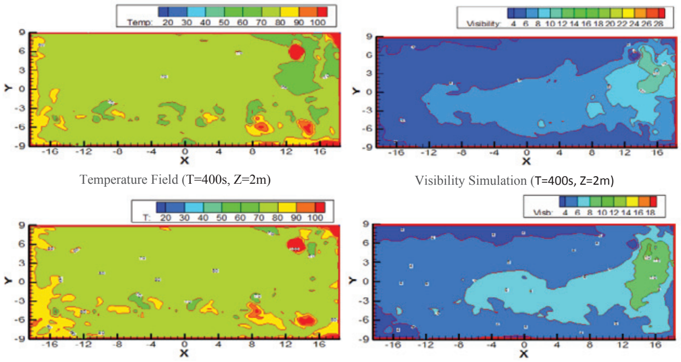
A field modeling of temperature and smoke phenomena in 4th Reading-Room was presented by FDS. ASET was estimated through the occurrence of critical hazard in the simulation.

- Initial conditions

a) The inner decoration materials accorded with regulatory requirements;
b) Normal temperature and pressure, the fire spread was free from the wind, namely wind speed was 0 m/s;
c) Mechanical ventilation system and work properly;
d) According to the calculation of RSET, simulation time was set 500s.

- The result

The simulation results were shown in Fig 3.



Temperature Field (T=400s, Z=2m) Visibility Simulation (T=400s, Z=2m)

Temperature Field (T=500s, Z=2m) Visibility Simulation (T=500s, Z=2m)

Fig.3. The simulation result of 4th reading room

when *T = 400s*, from 2m above the ground, the temperature of the flue gas was about 100°C, visibility was more than 4m, about 6m near the exit ; at the end of the simulation *(T = 500s*), the temperature didn't exceed the critical value of 180°C.

4. Result analysis and discussion

The simulation results showed that during RSET (409.74s) each part of the room didn't reach a dangerous state, which was a great threat to the safe evacuation of personnel. It can be inferred that ASET（＞500s) can assure a safe evacuation time for people.

Evacuation process which involved many uncertain factors was very complex. To simplify the calculation and analysis in the paper, a safety coefficient 1.5 was put forward; and in the calculation and simulation of RSET and ASET, the initial and boundary conditions were ideally assumed. Considering to the possible errors, it was necessary to extend ASET (the time of the fire reaching a dangerous state), and shorten RSET (the safety evacuation time) in practice.

- ASET. The method included the fire detector alarming as soon as possible, and/or the fire developing at a lower speed. Speaking specifically, by improving the sensitivity, increasing the number, and optimizing the layout of the probe, and additional mechanical Ventilation Smoke-Exhaust, optimization of the automatic sprinkler system, the time of the fire reaching dangerous state could be delayed, thus the time for the safety evacuation could be available.
- RSET. Safe evacuation time was affected greatly by subjective factor of man, such as density distribution, psychological and behavioral characteristics, etc. thus, specific measure include, implementation and strengthening proper safety education, regular fire drills and the like, increasing the width of the evacuation routes, and the number of exit and the like, could divert the occupant density, increase the evacuation speed, thus to shorten RSET (required safety evacuation time).

5. Conclusions and recommendations

A college library was analyzed according to performance-based fire and safety evacuation design. Fire load and the number of evacuation occupants was collected through field survey, and statistical calculation of RSET and simulation under fire-scenario given was made in the key regions, a comprehensive analysis of the library's safety evacuation performance was made. Conclusions are drawn as following:

- Through field survey, equipped with large amount of books, crowds of people, 1st, 3rd and 4th reading room were the key regions of fire-prevention and safety evacuation;
- Taking the large sum of readers during holidays and weekend into account, the record of the readers' number surveyed was repeated 3 times, and the average value was obtained and regarded as the evacuation number at different times; and the theoretical number of safe evacuation was calculated applying the formula. By comparing, the value surveyed was far less than the theoretical calculation, it was inferred that the evacuation number complied with the relevant regulatory requirements;
- Regarding to books load, evacuation distance and number of evacuation people, it was inferred 4th reading room was the most unfavorable region for safety evacuation. Under the fire scenario assumed. RSET was calculated according to

the empirical formula, and ASET was estimated by FDS simulation, getting RSET <ASET. The results indicated that the fire-protection system in 4thReading-Room could meet requirement of safety evacuation;

- By the analysis of performance-based fire-protection and safety evacuation design of the college library, it was inferred that the fire-protection safety systems could meet the demand.

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